INVESTIGATION OF MICROPHYSICS AND PRECIPITATION FOR ATLANTIC COAST THREATENING SNOWSTORMS (IMPACTS): THE 2022 DEPLOYMENT

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ABSTRACT

The Investigation of Microphysics and Precipitation for Atlantic Coast Threatening Snowstorms (IMPACTS) is a NASA-supported field campaign to study snowstorms particularly over the northeastern United States. Snowfall within these winter storms is often organized in banded structures that can vary on multiple scales. The goals of IMPACTS are to characterize the spatial and temporal scale of snowbands, understand the processes controlling the structure and evolution of the bands and apply this knowledge to improving remote sensing and numerical modeling. IMPACTS takes place over three winter seasons, 2020, 2022 and 2023. IMPACTS flies two aircraft: the ER-2 equipped with satellite-simulating remote sensing instruments; and the P-3 equipped with in situ microphysics probes and environmental instrumentation. Stationary and mobile radar facilities and mobile sounding teams round out the observational assets. The preliminary results from the 2022 deployment are highlighted here.

Index Terms—Field Campaigns, Remote Sensing of Snow, Microphysics

1. INTRODUCTION

Winter snowstorms impact major population centers across the eastern United States (US) causing school and business closings, power outages, and transportation disruptions [1]. Snowfall within these storms is often organized in mesoscale structures of increased snowfall rates called snowbands. The processes that contribute to the observed precipitation banding can vary on temporal and spatial scales. A larger primary band is found to the northwest of the surface low and is often associated with mid-level frontogenesis [e.g., 2, 3]. Other smaller mesoscale bands can form in a wide range of frontogenesis and moist potential vorticity environments [4]. Studies have pointed to a variety of mechanisms associated with mesoscale banding include elevated convection, generating cells, shear instabilities, and gravity wave activity [5, 6, 7, 8]. However, many aspects of snowbands at all scales still remain poorly understood, such as how bands form and evolve; how increased snowfall rates at the surface relate to the vertical variability of horizontal and vertical motions and thermodynamic instabilities; and how the microphysical properties and environmental conditions vary within and outside of snowbands.

Many regions across the globe lack direct measurements of precipitation due to their remote locations (e.g., over oceans) and as such depend on remote sensing of precipitation from space. The current Global Precipitation Measurement (GPM) mission [9, 10] includes a Core Observatory Satellite equipped with the first multiple-frequency radar flown in space, the Dual-Frequency Precipitation Radar (DPR) and a multi-frequency passive microwave radiometer, the GPM Microwave Imager (GMI). Although a key GPM objective is to detect and measure falling snow at the surface over a wide range of snowfall intensities, the current GPM algorithms are limited by uncertainties in snow amounts [10]. Unlike liquid precipitation, remote sensing of snow from space is complicated by the structural complexity of the individual snowflakes and their variable trajectories within and below the cloud. This complexity of snowfall properties can lead to uncertainties in remote sensing retrievals of precipitation rate [10].

In order to improve remote sensing algorithms of snowfall, ground-based and in situ observations of precipitation processes can provide additional insight and evaluate the uncertainty associated with retrievals. A recent GPM ground validation experiment, the GPM Cold Season Precipitation Experiment (GCPEx) [11] (Skofronick-Jackson et al. 2015) sampled snowfall resulting from frontal systems and lake-effect processes with aircraft and ground-based instrumentation. However, many of the events sampled during GCPEx had either rain or light snowfall and did not include snow resulting from banded structures within strong winter cyclones where snowfall rates can be particularly large. In contrast, The Investigation of Microphysics and Precipitation in Atlantic Coast Threatening Snowstorms (IMPACTS) is an ongoing NASA supported field campaign to sample snowband producing

processes within winter midlatitude storms across the northeastern US. IMPACTS consists of aircraft and ground-based observational assets. The satellite-simulating ER-2 aircraft flies above storm systems and is equipped with radars and passive microwave radiometers at wavelengths the same as those on current and planned satellite platforms. The in-situ P-3 aircraft flies within the clouds and is equipped with an array of microphysical probes and instruments that measure environmental parameters. These two aircraft sample in a coordinated fashion with the ER-2 above the P-3 on the same flight line so that the microphysical measurements by the P-3 can be directly related to the active and passive remote sensing measurements by the ER-2. Ground-based radars stationed at State University of New York at Stony Brook and on mobile trucks along with mobile sounding teams round out the observational network. The goals of IMPACTS are to characterize the spatial and temporal scale of snowbands, understand the processes controlling the structure and evolution of the bands and apply this knowledge to improving remote sensing and numerical modeling. Additional details about IMPACTS and the 2020 deployment season can be found in [12].

2. THE 2022 DEPLOYMENT

The 2022 deployment took place from 10 January through 28 February 2022. The instruments on the ER-2 were the same as in 2020 (3 radars sampling at 4 wavelengths, 2 passive microwave radiometers and the Cloud Physics Lidar, see [12]), and the instruments on the P-3 were mostly the same as those in 2020, except the Multi-Element Water Content System WCM-2000 instrument measuring liquid, ice and total water contents replaced the Nevzorov Probe (see [12] for full list from 2020). The ground network was upgraded to include 2 mobile radars and an additional sounding team. These mobile teams provided additional context to the aircraft data for storms that were sampled in the New York and New England areas. A total of 11 science flights were conducted in 2022, 8 of which were coordinated flights between the two aircraft. A wide variety of storm events were sampled including 2 Alberta Clippers, several strong frontal bands, and several deepening cyclones including one nor'easter type storm. In this section, we highlight preliminary results from a strong frontal system that produced heavy snowfall over the Chicago area. Since at the time of this writing the data quality control processes are ongoing, we are limited to the quicklook imagery and uncalibrated data.

On 17 February 2022, a deepening cyclone with a strong frontal band was the target of this science flight. Heavy snowfall was occurring on the northwestern side of the frontal band, depicted as a region of higher reflectivity values in the Multi-Radar/Multi-Sensor (MRMS) data. This region met the snowband criteria outlined in [4] and was sampled by both the P-3 and ER-2 aircraft (magenta ellipse and black line, Fig. 1). Vertical cross sections of reflectivity from the Ku-band (Fig. 2a,b) illustrate the finescale precipitation structures observed by the ER-2. The elevated region of higher reflectivity around 165 km from the southeast end of the flight leg (Fig. 2a) corresponded with the snowband observed by the ground-based MRMS network (Fig. 1). Meanwhile, the Ka-band reflectivity was impacted by non-Rayleigh scattering as shown by the dual-frequency ratio between Ku and Ka band ($DFR_{Ku\text{-}Ka}$) approaching 10 dB (Fig. 2b). These rather large $DFR_{Ku\text{-}Ka}$ values may be adjusted once calibrated data are available. Nevertheless, it is expected that the region will still indicate high values of $DFR_{Ku\text{-}Ka}$. What appears to be unusual in this case is that the area of enhanced DFR is large both vertically and horizontally.

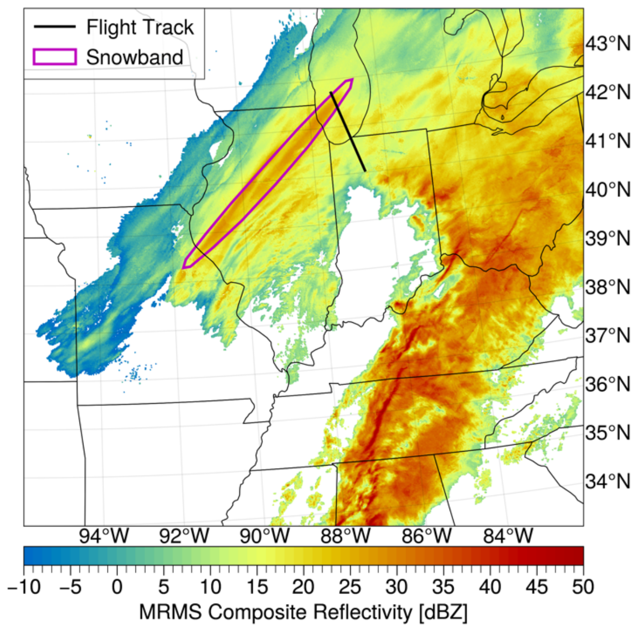

Figure 1*: Base reflectivity mosaic from the Multi-Radar/Multi-Sensor (MRMS) system valid 2230 UTC 17 February 2022 with the ER-2 and P-3 flight track as a black line. Snowband (magenta ellipse) objectively identified using methodology as in [4].*

The P-3 flew at an altitude of 3.5 km (T = -10°C) and observed mean particle sizes (D_m) up to 8 mm and aggregates exceeding 1 cm through the snowband (Fig. 2d, upper particle image strip in Fig. 2e). The distribution of particle sizes became broader in this region as well, indicative of a robust aggregation process. Estimates of the ice water content (IWC) varied considerably depending on the choice of mass-Dimension relationship, but each estimate showed a significant increase as the P-3 entered the snowband (Fig. 2e). Vertical motions at the height of the P-3 calculated from the Ka-band Doppler velocities in the same manner as described in [12] are upward at around 0.5 – 1.0 m s^{-1} in the vicinity of the snowband (Fig. 2c). Further west

at 90 km there was a couplet of downward and upward motions that corresponded to a slight increase in D_m and IWC (Figs. 2c-e) as well. At 135 km, there was another region of stronger upward vertical motions that corresponded to a local decrease in D_m and small particles (Fig. 2d, lower particle image strip Fig. 2e). The stronger vertical motions at this location could have been lofting smaller particles from below instead of enhancing aggregation as in the vicinity of the snowband.

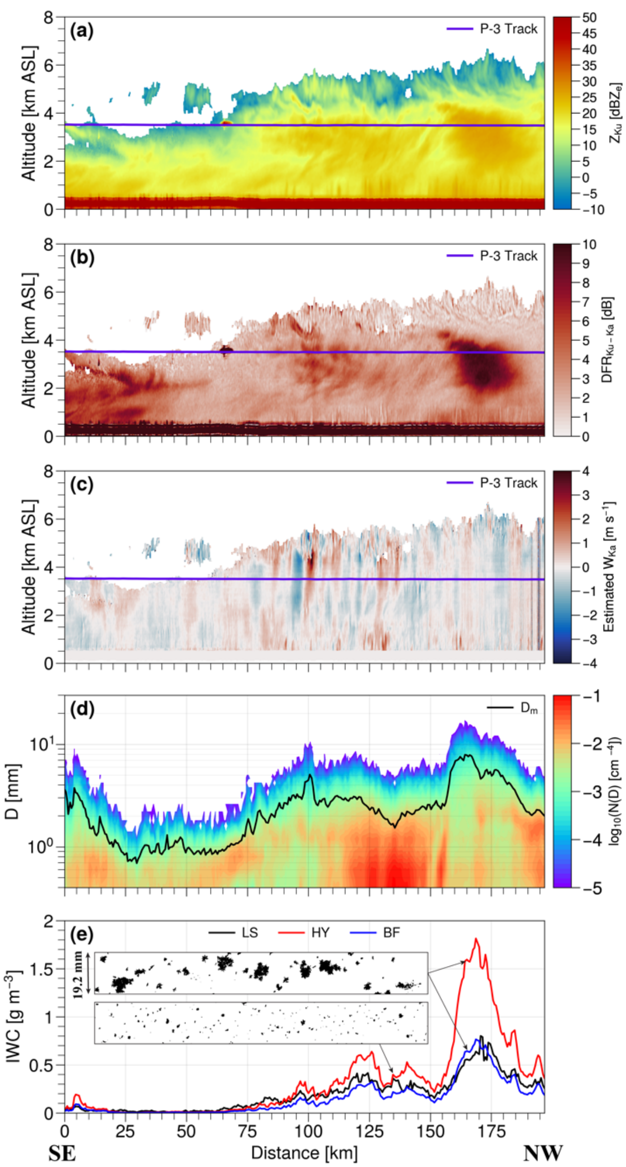

***Figure 2**: Cross-sections of (a) Ku-band, (b) dual-frequency ratio between Ku- and Ka-band (DFR$_{Ku\text{-}Ka}$), (c) estimated vertical velocity (m s^{-1}) calculated by adding the median of radial velocity at each altitude bin to the observed radial velocity measured by the Ka-band radar, (d) PSD (shaded) with mass-weighted mean diameter (D_m; black line), and (e) ice water content (IWC) using time-varying mass-Dimension (m-D) relationships aided by scattering simulations from [13] (black) and static m-D relationships from [14] (red) and [15] (blue) for the flight track in Fig. 1. Representative particle images from the High-Volume Precipitation Spectrometer (HVPS) in (e) are shown within and outside of the snowband (Fig. 1).*

The Cloud Particle Lidar attenuated total backscatter for the same flight leg is plotted in Fig. 3. It provides a view of the cloud top structure for this event. The location of the snowband at 170 km has the highest cloud tops (> 6.5 km) and the lidar is unable to penetrate very far into the clouds due to attenuation by larger particles as sampled by the P-3 (Fig. 2). In the region to the SE of the snowband around 120 – 160 km, the CPL shows a lot of variability in the cloud top structure and the lidar penetrated the clouds to heights varying between 4 – 6 km. The radar reflectivity from the Ku-band radar also indicated a lot of cloud top variability that is on the same scale as cloud-top generating cells at this location (Fig. 2a, c).

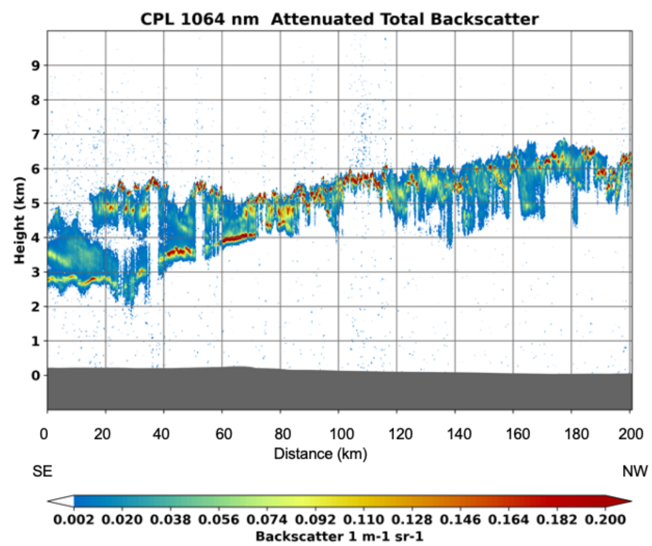

***Figure 3**: Cloud Particle Lidar (CPL) 1064 nm attenuated total backscatter for the same flight leg as shown in Figs. 1 and 2.*

This storm example illustrates the types of analyses that can be performed with coordinated measurements by the satellite-simulating ER-2 and the cloud-penetrating P-3 aircraft in snowstorms. This particular flight leg sampled a snowband that produced heavy snowfall over the Chicago area due to the presence of a snowband. The results shown here indicate that the snowband was associated with robust aggregation and an increase in ice water content compared to regions outside the snowband. Cloud top variability was also present in this case. Ongoing work analyzing other time periods from this flight, and other coordinated flights from the 2022 campaign will test the robustness of these results and provide insights into the processes that are commonly

present within snowband structures compared to outside of snowbands. This and other measurements obtained from IMPACTS will allow us to address the outstanding science questions described above.

4. ACKNOWLEGEMENTS

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5. REFERENCES

[1] Black, A. W., and T. L. Mote, "Characteristics of winter-precipitation-related transportation fatalities in the United States," *Wea. Climate Soc.*, **7**, pp. 133-145, 2015.

[2] Novak, D. R., L. F. Bosart, D. Keyser, and J. S. Waldstreicher, "An observational study of cold season-banded precipitation in Northeast U.S. cyclones," *Wea. Forecasting*, **19**, pp. 993-1010, 2004.

[3] Novak, D. R., B. A. Colle, and S. E. Yuter, "High-Resolution Observations and Model Simulations of the Life Cycle of an Intense Mesoscale Snowband over the Northeastern United States," *Mon. Wea. Rev.*, **136**, pp. 1433–1456, 2008.

[4] Ganetis, S. A., B. A. Colle, S. E. Yuter, and N. P Hoban, "Environmental conditions associated with observed snowband structures within northeast US winter storms," *Mon. Wea. Rev.*, **146**, pp. 3675-3690, 2018.

[5] Zhang, F., C. A. Davis, M. L. Kaplan, S. E. Koch, "Wavelet analysis and the governing dynamics of a large-amplitude mesoscale gravity-wave event along the East Coast of the United States," *Quart. J. Roy. Met. Soc*., **127**, 2209-2245, 2001.

[6] Plummer, D. M., G. M. McFarquhar, R. M. Rauber, B. F. Jewett, and D. Leon, "Structure and statistical analysis of the microphysical properties of generating cells in the comma-head region of continental winter cyclones," *J. Atmos. Sci.*, **71**, pp. 4181-4203, 2014.

[7] Rosenow, A.A., R.M. Rauber, G.M. McFarquhar and J.M. Keeler, "Elevated potential instability in the comma-head: Distribution and development," *Mon. Wea. Rev*., **146**, pp. 1259-1278, 2018.

[8] Keeler, J. M., B. F. Jewett, R. M. Rauber, G. M. McFarquhar, R. M. Rasmussen, L. Xue, C. Liu, and G. Thompson, "Dynamics of cloud-top generating cells in winter cyclones. Part II: Radiative and instability forcing," *J. Atmos. Sci.*, **73**, pp. 1529–1553, 2016.

[9] Hou, A. Y., R. K. Kakar, S. Neeck, A. A. Azarbarzin, C. D. Kummerow, M. Kojima, R. Oki, K. Nakamura, and T. Iguchi, "The Global Precipitation Measurement Mission," *Bull. Amer. Meteor. Soc*., **95**, pp. 701-722, 2014.

[10] Skofronick-Jackson, G. M., and 17 co-authors, "The Global Precipitation Measurement (GPM) mission for science and society," *Bull. Amer. Meteor. Soc.*, **98**, pp. 1679-1695, 2017.

[11] Skofronick-Jackson, G., M. and 16 co-authors, "Global Precipitation Measurement Cold Season Precipitation Experiment (GCPEx) for measurement's sake, let it snow," *Bull. Amer. Meteor. Soc.*, **96**, pp. 1719-1741, 2015.

[12] McMurdie, L. A. and 21 co-authors, "Chasing snowstorms: The Investigation of Microphysics and Precipitation for Atlantic coast-threatening snowstorms (IMPACTS) campaign.", *Bull. Amer. Meteor. Soc*., in review, 2022.

[13] Leinonen, J., and W. Szyrmer, 2015: Radar signatures of snowflake riming: A modeling study. Earth and Space Science, 2, 346– 358.

[14] Heymsfield, A. J., A. Bansemer, C. Schmitt, C. Twohy, and M. R. Poellot, 2004: Effective Ice Particle Densities Derived from Aircraft Data. J. Atmos. Sci., 61, 982-1003.

[15] Brown, P. R. A., and P. N. Francis, 1995: Improved Measurements of the Ice Water Content in Cirrus Using a Total-Water Probe. J. Atmos. Oceanic Technol., 12, 410-414.

[16] McMurdie, L. A., G. Heymsfield, H. E. Yorks, and S. A. Braun, "Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS) Collection. Data available online [http://ghrc.nsstc.nasa.gov/] from the NASA EOSDIS Global Hydrology Resource Center Distributed Active Archive Center, Huntsville, Alabama. Doi: http://dx.doi.org/10.5067/IMPACTS/DATA101